# Telefacturing based distributed manufacturing environment for optimal manufacturing service by enhancing the interoperability in the hubs

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## Abstract

Recent happenings surrounding the manufacturing sector, leads to intense progress towards development of effective distributed collaborative manufacturing environments. This evolving collaborative  manufacturing not only focus on digitalisation of this environment but also necessitates service-dependent manufacturing system that offers an un-interrupted approach to a number of diverse, complicated, dynamic manufacturing operations management at a common work place (hub). This research presents a novel telefacturing based distributed manufacturing environment for recommending the manufacturing services based on the user preferences. The first step in this direction is to deploy the most advanced tools and techniques i.e., Ontology based Protégé 5.0 software for transforming the huge stored knowledge/ information into XML schema of Ontology Language (OWL) documents and Integration of Process Planning and Scheduling (IPPS) for multi-jobs in a collaborative manufacturing system. Thereafter, we also investigate the possibilities of allocation of skilled workers to the best feasible operations sequence. In this context, a mathematical model is formulated for the considered objectives i.e., minimization of makespan, and total training cost of the workers. With an evolutionary algorithm and developed heuristic algorithm the performance of the proposed manufacturing system has been improved. Finally, to manifest the capability of the proposed approach with an illustrative example from the real time manufacturing industry is validated for optimal service recommendation.

## 1. Introduction

In this era of Information Technology, manufacturing industries accosting challenges due to globalization, high technology advancement, increased outsourcing, and high consolidation and at the same time an imminent movement (from rural to urban areas) of skilled technical labours has led to a risk(shortage of skilled labourers) to a greater extent. However, in today's scenario a substantial number of manufacturing units are getting distributed due to shorter product life cycles, customizations, and rapid advancements of information and communication technology where the strongest interconnections between geographically distributed resources (machines, manufacturing lines, plants and enterprises) can be possible. This highly efficient collaborative working environment, has led to a stiffer competition among the globally distributed manufacturing units. Therefore, in order to ensure high competiveness among them, Industries have change its trend from traditional manufacturing approaches and be able to swiftly design and manufacture products of any quantity yet highly customized (Khoshnevis, 2015).

In view of attracting the customers, manufacturing unit works in a distributed environment by dividing into small sub-companies having a distinctive fundamental business but centralized towards the production of specific group of products that gives an upper hand for the small and medium scale enterprise (SMEs) to compete in the global economy. On the other hand, manufacturing units even goes to the extent of sharing their skills, techniques, knowledge base to accomplish themselves in the ever changing global market (Paulo Leitão and Restivo, 2008)**.** Therefore, management of manufacturing functions inside the shop floor i.e., process planning and scheduling as well as enhancement of workers skill levels is of great interest, this has been clearly discussed in the later sections.

Process planning and scheduling are two important functions in any manufacturing system. Where, process planning specifies which tasks (operations, controls, transports and stores), to perform and scheduling refers to the allocation of resources in the shop over a planning horizon to manufacture the various tasks of the parts (Zhang, 2003). Obtaining the optimality by managing these two functions often conflict under traditional approach i.e., the manufacturing functions were carried out in a sequential manner, in which scheduling has been

performed after generation of the process plans. These process leads to possible loss of real time schedules (Bratoukhine et *al.* 2003, Wada and Okada, 2002; Cheng *et al.* 2001). In (Saygin and Kilic, 1999) the difficulties in traditional manufacturing approach and the obstacles to improve the productivity and responsiveness of the manufacturing systems have been clearly stated.

To overcome the above mentioned problems in traditional manufacturing approach in this customer driven market, integration methods have been proposed to resolve the dilemmas in manufacturing functions. In (Chryssolouris and Chen, 1985; and Chryssolouris, et al., 1984), the fundamental concept of process planning and production scheduling has been introduced. Till date numerous strategies and methodologies have been developed for enhancing the adaptability of the integration approach on manufacturing systems for acquiring better execution of the framework (Manupati, et al., 2012). As of late, much consideration towards agent/multi-agent based approach has been shown by number of researches for integrating the manufacturing functions, especially in distributed environment. Li and Chaoyang, (2006), made a detailed literature review on Integration of Process Planning and Scheduling (IPPS), particularly on agent based approach and its advantages over distributed manufacturing systems. An N-person non-cooperative game-theoretic approach to generate the optimal process plans for multiple jobs in a networked based manufacturing system has been presented (Zhou et al., 2010). To develop more effective and efficient solutions of the game, a hybrid adaptive genetic algorithm has been generated. The extension of the above work has been carried over by (Manupati, et al., 2015). In their work, a Hybrid-DNA based evolutionary algorithm was developed for acquiring feasible process plans of multiple jobs. At last, their results demonstrated significant improvement over other algorithms and better performance of the system.

Additionally, to compensate the shortage of skilled labours the implementation of different approaches inside the production system to enhance its control is highly desired. One such approach is teleprocessing based manufacturing support system, called as Telefacturing. We define Tele manufacturing as the activity where a firm utilizes services afforded via communication networks and across information superhighways to perform, in real time, operations and processes necessary to the design and production of items (Carl Wolf et al., 1996). Henceforth, to alleviate the above mentioned issue of non-availability of skilled workers, the current paper presents a new paradigm in the distributed manufacturing

environment i.e., Telefacturing which isolates the workforce and the factory. Where, the enterprises are established in such a way that it can function in areas which is more suited for manufacturing processes with lower tax rates and land values, whilst the workers can perform and reside in areas they wish such as metropolitan and urban areas. In this kind of pattern, workers in distant locations can be able to perform their job remotely by simply controlling robots, remote sensing and other telecommunication devices (Khoshnevis, 2015).

However, in such a geographically distributed environment, the most challenging part is the collaboration and coordination among enterprises for mutually exchanging the information. It has been stated that an ontology may be considered as a mode for interoperating all application software that can share the information during coordination by (Panetto, et al., 2012). Interoperability is defined as capability of heterogeneous systems or components to communicate information and to utilize the data that has been exchanged. Though, the system or components are heterogeneous, they are interlinked with each other through a network. As our primary intention is to ascertain that all the entities like machines, humans, software agents, suppliers can reciprocate information and knowledge without any significant loss of data. Owing to this, the necessity of interoperability has led to following prerequisites; all the data shared by various agents must be systematised in a common form and it is to be garnered in an ontology. Approach to this ontology has to be ensured by using common language, adaptability to each entity (Daniel, et al., 2004).

Motivated by these factors, we have explored the possible issues which may arise in real-time (Virtually) implementation of Telefacturing approach. In this study, we have concentrated on two aspects, Initially, Integration of process planning and scheduling in a proposed approach and later, predicting the workers skill level and then enhancing their skills to perform multiple tasks from a common place (Hub) thereby minimising the processing time of each worker by assigning optimal appropriate tasks in a hub. In telefacturing, as all the enterprises have to communicate with hubs (common place for workforce) to synchronise the varied tasks in a system of enterprises, machines, shop floors, suppliers, interoperability issue may arise. All the jobs among the enterprises and the hubs and vice versa in a telefacturing environment may have diverse control systems, exchange of information related to business processes, product data and documents to the hubs has become tedious. Hence, to enhance the interoperability and to solve the communication among the enterprises and hubs it is necessary to develop a common language which is light in weight and easy to transferrable. Therefore,

we introduced ontology based XML (Extensible Mark-up Language) files which can be used as a common language to transfer the diversified information without any interruption and mutual exchange of massive data. In order to support the customer to access such a large data, queries were made possible with the Ontology. In the quest to achieve the above mentioned requirements, a framework has been developed with telefacturing approach and with a case the effectiveness of the model is tested. Moreover, a heuristic has been developed to determine the qualified worker among trained skilled workers for performing the multiple tasks at the hub according to the availability of the job. Consequently, the objectives such as minimising the processing time of each worker by assigning optimal appropriate tasks in a hub and henceforth reducing the workload of each hub.

In section 2, we have briefly discussed telefacturing approach and developed a framework model based on it. In section 3, we have used a software Protégé 5.0 to develop an Ontology representing a knowledge about Jobs, Machine, Process Plans, Operating Time etc., and later XML files are generated. In section 4, we presented a case study. Section 5, experiments with real time data and explains the algorithm for proposed method. In section 6, discussions about results were specified. In section 7, we have concluded with providing insights about the future work.

## 2. Collaborative Telefacturing environment

Telefacturing is a new kind of distributed manufacturing environment where it enables the integrated information/knowledge right from product design to manufacturing with capability of sharing resources between geographically distributed enterprises. In general, the enterprises are located in rural areas where the cheaper land costs are favourable. In the proposed telefacturing approach, factories could setup hubs in the closer proximity range to the residential areas. This Virtual hub will act as an alliance of enterprises that are willing to share their skills, core competencies, and resources so as to respond swiftly to the market demands. In the near future, Possessing or operating hubs of these kinds can also emerge as a potential business idea, as these hubs can also turn to be a common workplace for number of factories. This collaborative service support system is capable of carrying out customer requests through manufacturing information network (application service layer) through virtual agents. It provides enterprises with resources such as capabilities and processes that are highly expensive and too complicated. It makes use of expertise of various groups situated at various geographical areas and integrates distributed processes into common manufacturing process.

Additionally, for the workers who do not like to work alone in home, the hub is a place where the workers can socialize with other fellow employees (Khoshnevis, 2015).According to the proposed concept of Telefacturing, we present a framework model, which is illustrated in Figure 1. It is developed by incorporating three degree networked structure (user/application/simulation).
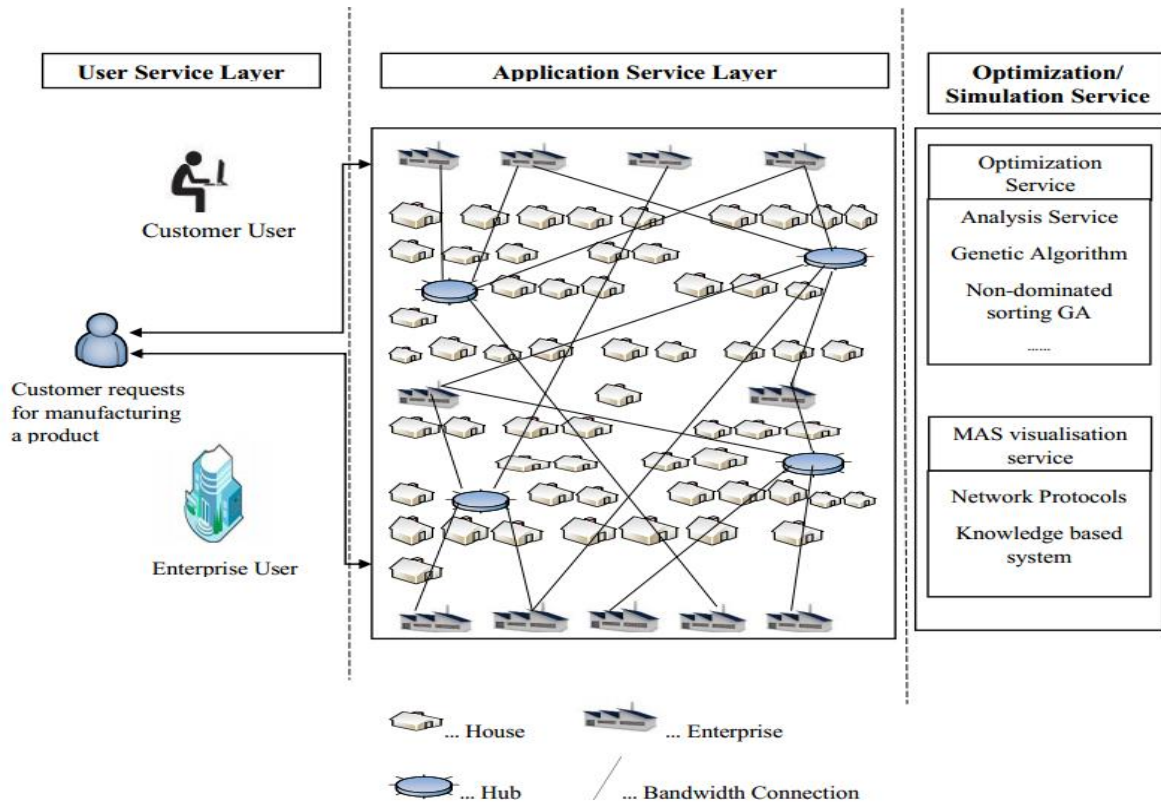


**Fig 1**. Framework of the proposed telefacturing approach.

In this aforementioned approach, the process initiates with a customer requests whose work task can be taken care by network based manufacturing service by means of either Customer User (CU) or Enterprise User (EU). Customer user is basically an organization which gets requests for manufacturing from the customer's and to evaluate the tasks (Identifying the related enterprises, interaction with servers and customer) with help of their decision system. However, each customer has their own data base and their own supporting system from which the enterprises can be chosen according to the task to be perform so as to provide a profitable solution in productive manner. Analysing manufacturing requests from multiple organization is also possible here. Whereas, the Enterprise user because of its self-service providing capability (it has the facilities to perform some of the tasks of Customer requests) part of the work can be taken care by EU itself. The remaining operations can be

chosen (as to select potential enterprise for carrying out customer requests) from their available database in the application service layer. In this manner, CU and EU are able to achieve diverse and more challenging production tasks that are unaccomplished by a single enterprise (Zhang et al., 2010). After acquiring required product data and the enterprise's information, a suitable approach to define the task requirements and its implementation in distributed environment is carried out.

Here, the jobs data can be exchanged and their operations can be performed through limited/higher bandwidth Internet connections, allowing the workers with the flexibility to operate the machines at the shop floor either being in home or at dedicated hubs. Additionally, workers in distant locations can be able to perform their job remotely by simply controlling robots, remote sensing and other telecommunication devices. This proposed approach offers copious advantages such as the dependency on manual workforce and the consequent errors and injuries can be uprooted by minimizing human exposure to various potential health hazards. Manual labouring errors not only injure people, but can also account for momentous economic loss by damaging machineries and tools. As mentioned earlier, it can also repress the operating costs by using modest land for operation. In addition to that, a tele-operated factory does not have to comply with vital human requirements for lighting, food and other services. Conjointly this approach allows for lower operating costs. Another noteworthy aid is that, telefacturing factories can accommodate minimal number of engineers and technicians sufficient enough to rectify certain issues like replacement of worn out parts. In fact, to perform tasks with the above mentioned virtual environment, it is necessary to have detail information of the system configurations and its setup, this will be investigated in our future work. In this work, our main idea is to improve the hubs and enterprises operations thereby proper integration of both and also to improve the performance of the system. Telefacturing is also environment friendly in the fact that it preserves the required time and energy for commuting workers from long distance during rush hours, as it gives them the flexibility to work from less populated areas with customized time schedule (Khoshnevis, 2015).

## 3. Ontology knowledge for Telefacturing environment

In a telefacturing environment the manufacturing tasks are related to planning, allocation, ordering, machining of parts, assembling etc. Therefore, it is necessary to e-standardize the

resources that can be helpful for sending and exchanging the information. It can be accomplished by using Ontology and it is defined as the means of knowledge representation. It is able to provide all the definitions of components or systems and their communications in distributive environment so as to make a common understanding for reciprocation of information (Lin and Harding, 2007). RDF and OWL files generated from an Ontology are World Wide Web consortium (W3C) standard semantic language for publishing, sharing of information across online. (Jinag et al., 2010).

In order to achieve the above standardization, in this diversified distributed manufacturing system, addressing interoperability is the key. Many authors have decomposed interoperability into several layers. However, European Interoperability Framework (EIF) have categorised interoperability into three layers: technical, semantic, organizational. Technical Interoperability deals with issues related to connecting computer system and services. Such issues are data mixing, data exchange, security related, and interlinking services. Whereas, Semantic Interoperability deals with validating that the exact definition of exchanged data is understandable by applications other than originally intended applications. Organizational interoperability deals with business administration, goals and processes to amalgamate organizations that are willing to exchange information. Open standards like XML, Ethernet will help to overcome the issues of technical interoperability (Daniel etal.,2007).
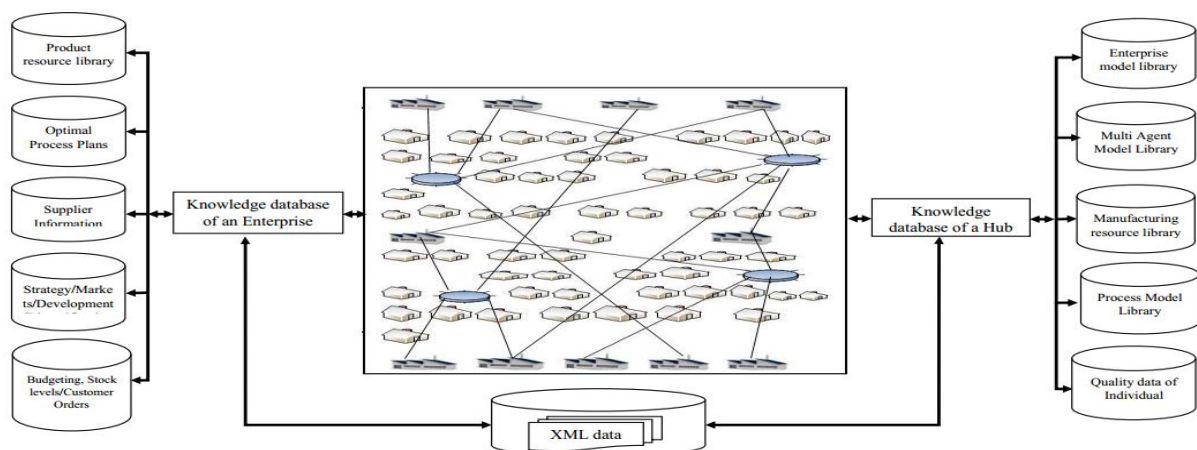


**Fig 2**. Framework illustrating databases of Hub and Enterprise.

One of the primary need of this environment is collaborative information management system (Tian et al, 2007), where it can be able to offer its support to geographically distributed enterprises in completing the task collaboratively in many ways. Fig 2. Illustrates database

framework for the proposed telefacturing approach where it consists of two modules: enterprise and hub database. An enterprise database is used to save the product resource information, BOM, process plans, engineering drawings, supplier related information, etc. for maintaining the consistency of enterprise's data and to reduce data termination. Here, the primary knowledge for enterprise and task evaluation is kept in hub database that offers support to the selection of potential enterprises, valuation of manufacturing capabilities of the enterprises, quality control service, profits, production status and so on. The above mentioned approach of storing the information in databases will help to resolve the problem behind exchanging and integration of diversified information structure in the telefacturing environment. In the next sections the proposed approach implementation over real case with proto type example is carried.

## 4. Case Study of telefacturing based manufacturing system

This case study has been taken from a medium scale industry which is located in southern part of India. Region of this industry has evolved into a potential manufacturing base that includes several other enterprises. All these enterprises supplement with each other to manufacture a specific range of products. Due to prevalence of problems such as interoperability, high labour costs, shortage of skilled labourers etc., these industries are hardly competitive in the global manufacturing scenario. In order to overcome all the above issues, industries are analysing the possibility of incorporating collaborative manufacturing techniques. In light of these developments, companies need to find enterprises with similar interests to enhance their manufacturing resources. We have considered a set of jobs submitted by different customers denoted as $n$. Each job has number of alternative process plans representing various ways of sequential operations. In other words, number of machines may perform different operations for alternative process plans. On the other hand, in this proposed manufacturing methodology, alternative machines are located in different geographical areas to perform the required operations on the job. This could be one of the difficult tasks in present manufacturing approach containing heterogeneous support systems. Due to flexibility of the proposed method, integration of process planning and scheduling helps us to make an optimal process plan, even though transportation time between machines are vital for process plan and scheduling. The objective of this paper is to provide an approach that can minimize the makespan of multiple jobs and to identify the qualified worker for performing tasks in the hub with a motive to minimize the processing time for each worker, thereby determine the total training cost for

each worker. The mathematical model for the above mentioned two scenarios is formulated as follows:

## 4.1. Phase I: Minimizing the makespan to complete the multiple jobs of distributed enterprises.

Table. 1 The notations used to explain the proposed mathematical model

| $N$ | total number of jobs |
|---|---|
| $K$ | total number of machines |
| $G_j$ | The total number of alternative process plans of job $j$. |
| $U_{jop}$ | The $o^{th}$ operation in the $p^{th}$ alternative process plan of job $j$ |
| $Q_{jp}$ | The number of operation in the $p^{th}$ alternative process plan of the job $j$ |
| $Tj$ | makespan of $j^{th}$ job from the set of possible process plans |
| $Prt_{jopm}$ | The processing time of the operation $Ujop$ on machine $m$ |
| $Trt$ | transportation time |
| $M$ | Any machine |
| $V$ | The maximal number of generations |
| $W$ | number of generation for job scheduling game |
| $st (j, o, p, m_1 )$ | Starting time of operation $j^{th}$ job and $p^{th}$ process plan and $o^{th}$ operation on machine1 (one of the machines on which $o^{th}$ operation of $p^{th}$ process plan of $j^{th}$ job is done) |
| $trt (j, p, m_1, m_2)$ | transporting time for $j^{th}$ job and $p^{th}$ process plan from machine1 to machine2 |
| $wt (j, o, p, m)$ | Waiting time of operation $j^{th}$ job and $p^{th}$ process plan and $o^{th}$ operation on machine. |
| $f (j, t)$ | fitness function for each individual in the population |
| $A$ | A very large positive number |
| $C_j$ | The completion time of job $j$ |
| $C_{jopm}$ | The earliest completion time of operation $U_{jop}$ on machine $m$ |

**Mathematical Model:**

Minimization of makespan $Z= Max\ C_{jopm}$ (1)

*Subject to Constraints:*

The first operation in the alternative process plan $p$ of job $j$ is indicated as

$$C_{j1pm} + A(1\text{-}X_{jp}) \geq pt_{j1pm} \tag{2}$$

$j \, \varepsilon \, [1, N], \, p \in [1, G_j], \, m \, \varepsilon \, [1, K]$

The last operation in the alternative process plan $p$ of job $j$ is indicated as

$$C_{jQ_{jp}pm} - A(1 - X_{jp}) \leq C_{jopm}$$
$$j \in [1, N], \, p \in [1, G_j], \, m \in [1, k] \tag{3}$$

Different processes for a job expressing different operations that are unable to be processed simultaneously.

$$C_{jopm} - C_{j(0-1)pm_1} + A(1 - X_{jp}) \geq Pt_{jopm}$$
$$j \in [1, N], \, O \in [1, Q_{jp}], \, p \in [1, G_j], \, m, m_1 \in [1, K] \tag{4}$$

Each machine can only process one operation at a time this can be expressed as a constraint for the machine.

$$C_{jopm - Cqrsk} + A(1 - X_q) + AY_{jopQrsm} \geq Pt_{jopm}$$
$$j, Q \in [1, N], \, r \in [1, Q_{jprs}], \, O, p, S \in [1, Gj, p], \, m \in [1, K] \tag{5}$$

One alternative process plan can be selected for each job

$$\Sigma_1 X_{jp} = 1$$
$$p \in [1, G_j] \tag{6}$$

Only one machine should be selected for each operation.

## 4.2. Phase II: Minimizing human processing time for hubs effective performance

Objective Functions:

$$MinZ_1 = \sum_{p=1}^{P} \sum_{q=1}^{Q} \sum_{l=1}^{L} C_{pq}^l \theta_{pq}^l \tag{7}$$

Constraints:

$$\sum_{q=1}^{q} \phi_{pq} = 1 \ \forall p \tag{8}$$

$$\sum_{l=1}^{l} \theta_{pq}^{l} > 1 \quad \forall p \ \phi_{pq} = 1 \tag{9}$$

$$\sum_{p=1}^{P} \sum_{q=1}^{Q} \theta_{pq}^{l} = 1 \quad \forall l \tag{10}$$

$$1 \leq \sum_{p=1}^{P} \phi_{pq} \leq W_{q} \quad \forall q \tag{11}$$

$$1 \leq \sum_{p=1}^{W} G_{pq} \quad \forall q \tag{12}$$

$$\sum_{q=1}^{Q} \sum_{l=1}^{U} H_{uql} = 1 \ \forall q \tag{13}$$

$$\sum_{u=1}^{U} \sum_{l=1}^{U} H_{uql} = 0 \quad (\forall q \ \sum_{p=1}^{W} G_{pq} = 0) \tag{14}$$

$$\sum_{Q=1}^{q} \sum_{L=1}^{U} H_{uql} \leq \sum_{q=1}^{Q} \sum_{L=1}^{U} H_{(u=1)q'L} \quad u=(2,3....U) \tag{15}$$

The aforementioned objectives, i.e., minimizing the total cost incurred for training all workers (Z1), minimization of the sum of squares of deviations from mean of processing times for all workers in each hubs(Z2), minimization of human processing time for hubs effective performance (Z3) are given by Eq. (7), respectively. Eq. (8) ascertain that a worker is allocated for performing of job at one hub. Hence, the movement of workers among hubs is not preferred. Eq. (9) represents that each worker in a hub can perform more than one operations of a product. Literally, it shows that workers in hubs have multiple skills, which is different from that in the original conveyor assembly line. Eq. (10) ensures that an operation in a particular hub is only performed by one worker. Work sharing among workers is not taken in to consideration. Eq. (11) is the reducing worker (s) constraint that the total number of workers in the cell system needs to be smaller than that of the assembly line. Eq. (12) is the rule of cell formulation, which ensures that each formatted cell should contain at least one worker. Eq. (13) is the assignment rule by which a product batch is only assigned to a cell. Eq. (14) is the rule of assigning constraint; that means a product must be assigned to cell in which a worker is assigned at least. Eq. (15) is the assignment rule by which product batches must be assigned sequentially.

## 5. Experimentation and discussion

In order to prove the effectiveness of concepts, methodology, architecture and techniques of the proposed telefacturing approach, we have experimented the telefacturing environment for distinct product requests from various customers and available machines in the distributed environment.

### 5.1. Implementation based on Ontology

Ontology offers all the information about the resources used in the enterprises like Equipment data, Human resources, Operation task related data, Product type data, Process time etc., Ontology based approach enables affiliation of all the information communicated between the systems/components in a collective framework. This unification of all the data helps to overcome the interoperability issue in heterogeneous environment. With Fig. 3 We have shown the used Protégé 5.0 to develop an ontology representing a domain of 6 distinct product requests from various customers and 8 different machines located geographically.
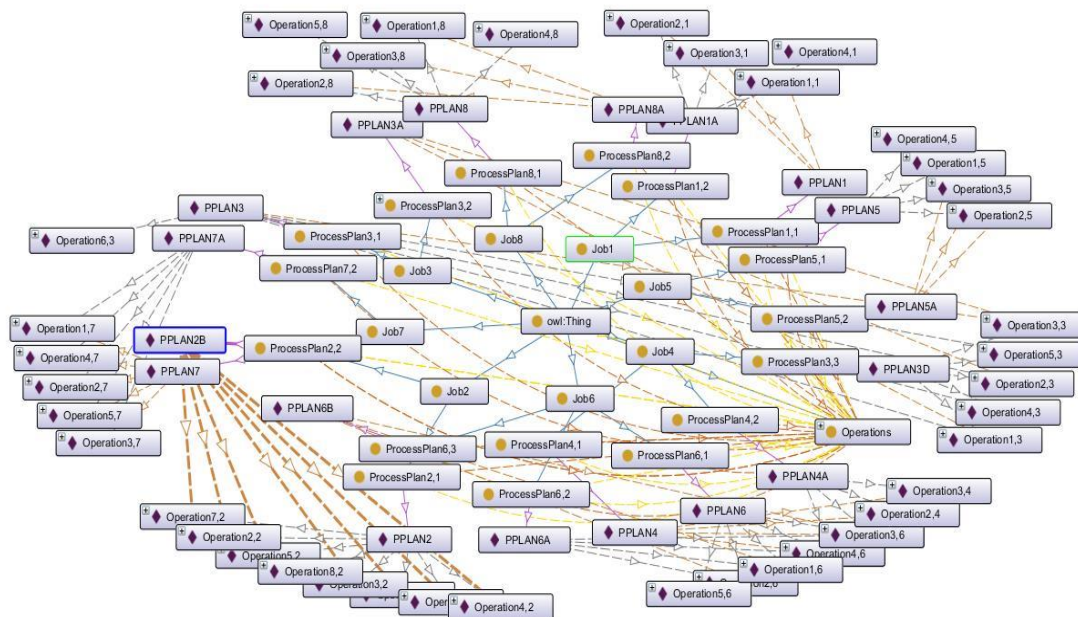


**Fig 3**. Development of Ontology.

### 5.1.1. Generation of XML/ RDF files

The platform for sharing information across the virtual network is crucial to enable various information services to the customers. Data related to the product that are available in enterprise's database are often comes in particular CAD format and files are larger in size. Hence it is necessary to translate the data into web-supported format (XML) to make it available across the entire network. Fig 4. Shows that the conversion can be supported by using Protégé 5.0 software. It uses previously stored ontology data to generate XML files. As mentioned earlier, XML format is the feasible way of transferring data across the network of heterogeneous system. On the other hand, another noteworthy aid is that it doesn't require installation of any other software's for searching and viewing. To assist users in processing their queries, a platform for making queries was developed as shown in Fig 5.
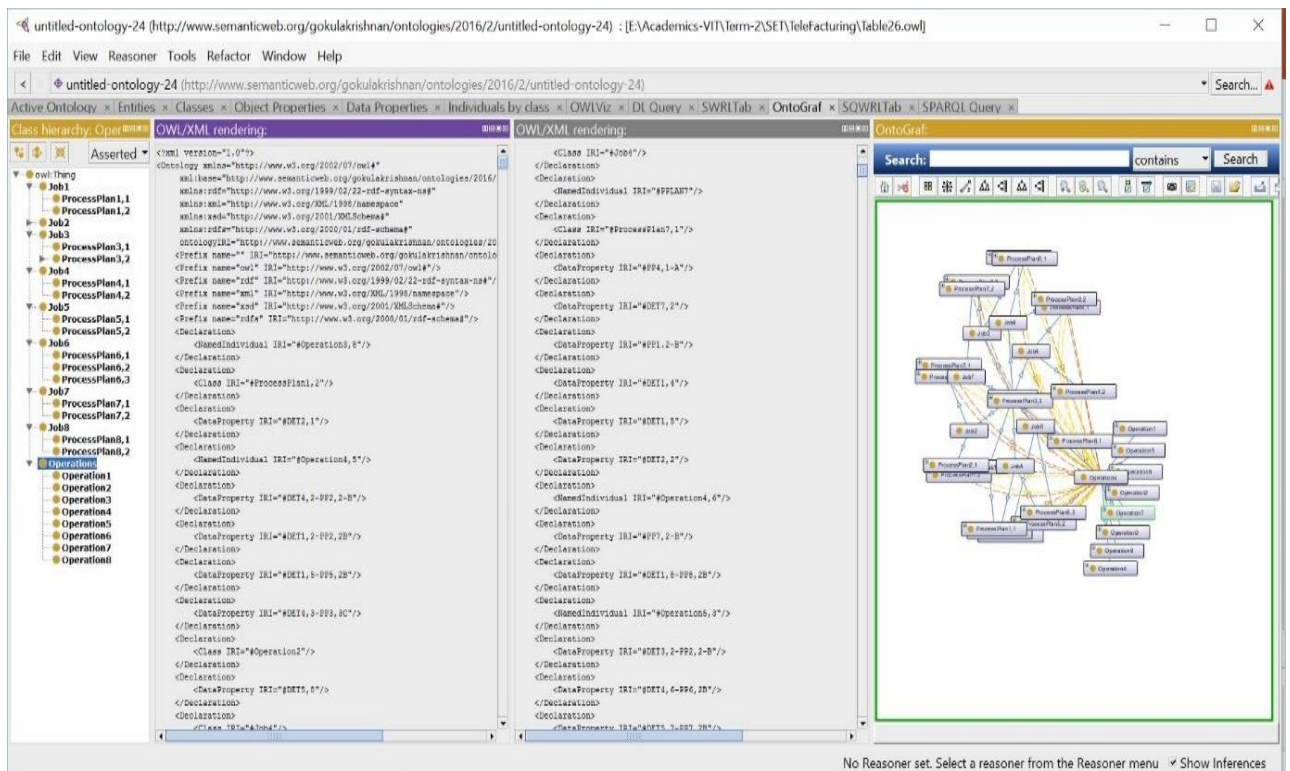


**Fig 4**. Snapshot of the generated XML file.
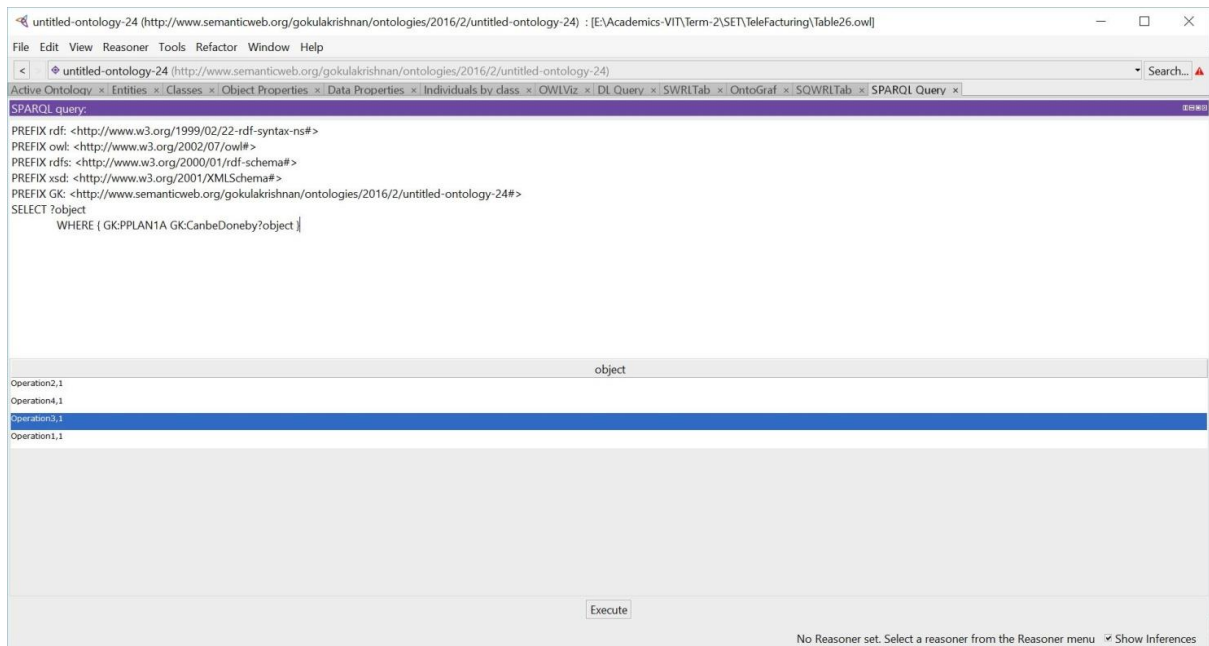
**Fig 5**. Generation of SPARQL Query.

It is important to maintain the data properly without any conflicts for efficient query. In this way, clients can look into large amount of data and resources of enterprises in the distributive environment. SPARQL query was made available online, enabling customer query services accessible across all the hubs.

## 5.2. Minimisation of Makespan with evolutionary algorithm based approach

The proposed telefacturing approach has been implemented in real time manufacturing scenario was used for effective implementation. Here, the case study consists 6 job requests from varied customers and 8 available machines that are assumed to be geographically distributed with the transportation time shown in Table 2 and 3.

In this telefacturing environment, each job has a set of process plans and for each operation number of geographically distributed machines are available. The data in the curly bracket indicates machine no's and the data in the square bracket indicates processing time for particular operation.

**Table 2**. Input data for 6x8 problem

| Job | PP | Operations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | O$_1$ | O$_2$ | O$_3$ | O$_4$ | O$_5$ | O$_6$ | O$_7$ | O$_8$ |
| J$_1$ | PP$_{1,1}$ | {1,2,7,8} [6,5,5,4] | {3,4,5} [7,6,6] | {6} [8] | | | | | |
| | PP$_{1,2}$ | {1,3} [4,5] | {2,4} [4,5] | {3,5} [5,6] | {4,5,6,7,8} [5,5,4,5,9] | | | | |
| J$_2$ | PP$_{2,1}$ | {2,7} [4,8] | {1,3,8} [2,3,8] | {2,4,6} [4,3,5] | {3,5} [2,4] | {2,4} [3,4] | {4,6} [3,5] | {1,3,5} [5,5,8] | {4} [2] |
| | PP$_{2,2}$ | {1,3,5} [1,5,7] | {4,8} [5,4] | {4,6} [1,6] | {4,7,8} [4,4,7] | {4,6} [1,2] | {1,6,8} [5,6,4] | {4} [4] | |
| J$_3$ | PP$_{3,1}$ | {2,3} [5,6] | {1,4,7,8} [6,5,4,7] | {2,5,7} [5,6,5] | {3,6} [6,5] | {1,6} [6,6] | {5} [4] | | |
| | PP$_{3,2}$ | {1,8} [7,8] | {3,4,7} [8,8,11] | {5,8} [9,8] | | | | | |
| | PP$_{3,3}$ | {2,3,8} [7,6,8] | {4,8} [7,7] | {3,5,7} [7,8,7] | {4,6} [7,8] | {1,2} [1,4] | | | |
| J$_4$ | PP$_{4,1}$ | {1,2,7,8} [7,8,7,8] | {3,4} [7,6] | {6} [9] | {1,7} [5,7] | | | | |
| | PP$_{4,2}$ | {1,3,5} [4,3,7] | {2,8} [4,4] | {3,4,6,7} [4,5,6,7] | {5,6,8} [3,5,5] | | | | |
| J$_5$ | PP$_{5,1}$ | {1} [3] | {2,4} [4,4] | {3,8} [4,4] | {5,6,8} [3,3,3] | | | | |
| | PP$_{5,2}$ | {2,4,7,8} [5,6,5,5] | {5} [7] | {3,6} [9,8] | | | | | |
| J$_6$ | PP$_{6,1}$ | {1,2} [3,4] | {3,4} [4,3] | {2,5,7,8} [5,3,5,4] | {3} [4] | {4,5} [4,6] | {3,6} [5,4] | | |
| | PP$_{6,2}$ | {1,3} [4,4] | {2,3} [5,6] | {2,4,7,8} [6,7,5,6] | {6} [7] | | | | |
| | PP$_{6,3}$ | {1,2,3} [3,5,6] | {4,5} [7,8] | {3,6} [9,8] | | | | | |

**Table 3**. Transportation time for 6×8 problem

| Machine | M$_1$ | M$_2$ | M$_3$ | M$_4$ | M$_5$ | M$_6$ | M$_7$ | M$_8$ |
|---|---|---|---|---|---|---|---|---|
| M$_1$ | 0 | 3 | 7 | 10 | 3 | 5 | 8 | 12 |
| M$_2$ | 3 | 0 | 4 | 7 | 5 | 3 | 5 | 8 |
| M$_3$ | 7 | 4 | 0 | 3 | 8 | 5 | 3 | 5 |
| M$_4$ | 10 | 7 | 3 | 0 | 10 | 8 | 5 | 3 |
| M$_5$ | 3 | 5 | 8 | 10 | 0 | 3 | 7 | 10 |
| M$_6$ | 5 | 3 | 5 | 8 | 3 | 0 | 4 | 7 |
| M$_7$ | 8 | 5 | 3 | 5 | 7 | 4 | 0 | 3 |
| M$_8$ | 12 | 8 | 5 | 3 | 10 | 7 | 3 | 0 |

In order to obtain good approximate solutions, the most popular, efficient and widely used genetic algorithm based evolutionary algorithm has been used. The algorithm have been coded in MATLAB software and the problem is tested on Intel® Core™2 Duo CPU T7250 @2.00GHz, 1.99 GB of RAM. The result of this problem i.e., average maximum time taken for completion of the job for given manufacturing scenario have been shown in Fig 8. To get a precise conclusion, the problem of this manufacturing approach was solved at an average for 20 simulation results and the corresponding result was represented as Gantt chart. As shown in the Fig 6. It can be understood that average time taken for completion of all the jobs (makespan) is 150 minutes.
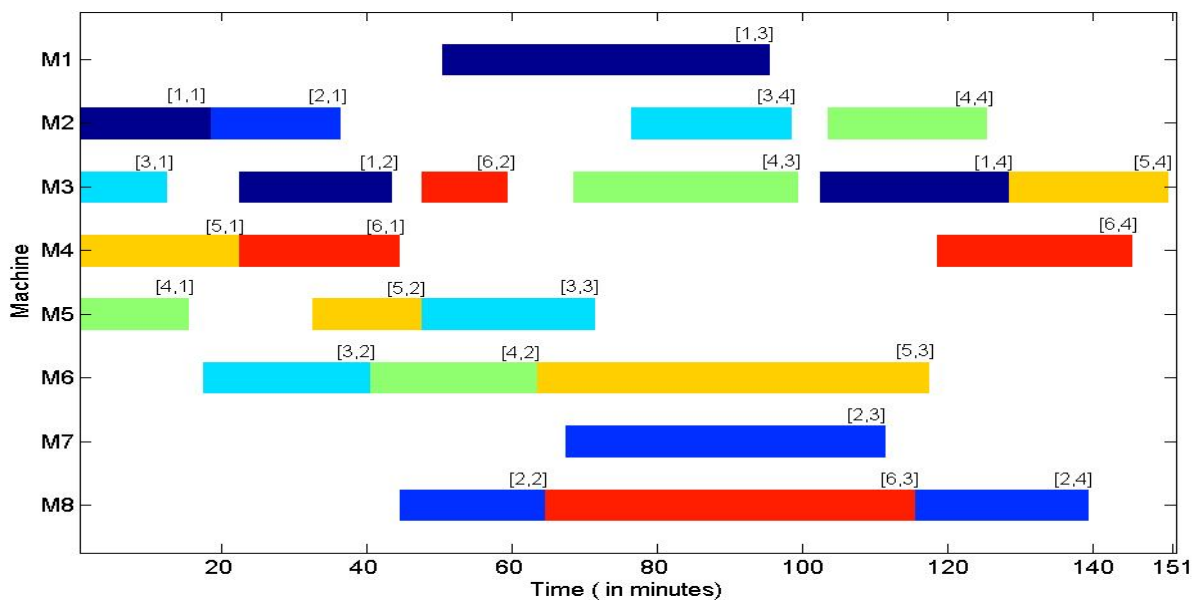


**Fig 6**. A Gantt chart showing optimal process plan decision for 6×8 case.

### 5.3 Heuristic approach to find the total cost for the hubs

As mentioned earlier the above mentioned problem is complicated. Therefore, in order to find our proposed objective, i.e., allocating workers to hub for performing required operations, we have used a Heuristic approach as given below in Fig 7.

In Table 4. the average time required for each operation of each job type prior to training has been given. The symbol "/" indicates that there is no operation for corresponding Job type. In

Table 5. "0" indicates that worker already has required skill for performing that particular operation and the sign of "/" denotes that particular operation is not necessary in the job and hence training is not required. This computational case has been solved using MATLAB programming.



**Fig 7.** Flowchart of Heuristic approach for assigning Jobs to workers.

**Table 4**. The average time required for each operation of each Job type before the training has been given for the worker.

| Jobs | Operation 1 | Operation 2 | Operation 3 | Operation 4 | Operation 5 | Operation 6 | Operation 7 | Operation 8 |
|---|---|---|---|---|---|---|---|---|
| Job1 | 81 | 50 | 95 | 93 | 87 | 67 | 79 | 74 |
| Job 2 | / | 73 | / | 78 | 69 | 95 | / | 93 |
| Job 3 | 84 | 82 | 63 | / | 69 | / | / | / |
| Job 4 | 86 | / | 70 | 66 | 71 | 54 | 89 | 58 |
| Job 5 | 92 | 88 | 88 | 63 | 50 | 63 | 56 | 79 |
| Job 6 | 82 | 63 | 86 | 95 | / | 67 | 61 | 80 |

**Table 5**. The cost incurred for training each worker for each operation of each Job type.

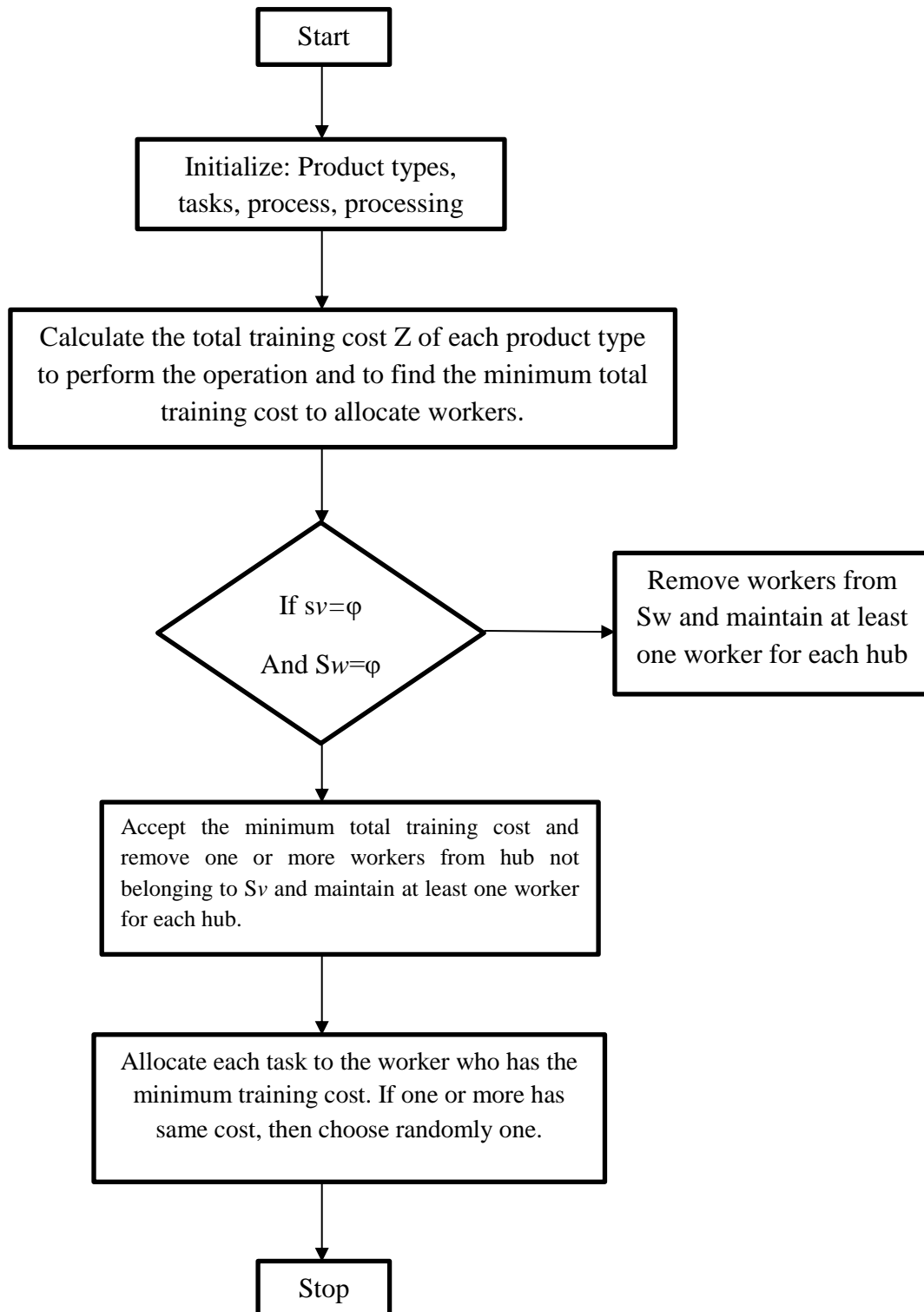| Job | Worker | Operation 1 | Operation 2 | Operation 3 | Operation 4 | Operation 5 | Operation 6 | Operation 7 | Operation 8 |
|---|---|---|---|---|---|---|---|---|---|
| Job 1 | 1 | 0 | 30 | 56 | / | 20 | 62 | / | 36 |
| | 2 | 62 | 0 | 158 | / | 109 | 92 | / | 54 |
| | 3 | 53 | 1 | 0 | / | 50 | 49 | / | 90 |
| | 4 | 102 | 145 | 151 | / | 62 | 87 | / | 96 |
| | 5 | 80 | 90 | 43 | / | 0 | 132 | / | 77 |
| | 6 | 15 | 67 | 67 | / | 122 | 0 | / | 118 |
| | 7 | 96 | 146 | 32 | / | 167 | 135 | / | 55 |
| | 8 | 49 | 10 | 101 | / | 169 | 123 | / | 0 |
| | 9 | 147 | 136 | 23 | / | 83 | 104 | / | 132 |
| | 10 | 61 | 81 | 31 | / | 140 | 161 | / | 105 |
| Job 2 | 1 | 0 | 11 | 105 | 9 | 70 | / | 176 | 84 |
| | 2 | 48 | 0 | 179 | 90 | 106 | / | 6 | 122 |
| | 3 | 63 | 167 | 0 | 64 | 146 | / | 68 | 67 |
| | 4 | 110 | 39 | 23 | 0 | 123 | / | 133 | 8 |
| | 5 | 130 | 109 | 62 | 55 | 0 | / | 87 | 136 |
| | 6 | 86 | 60 | 60 | 45 | 86 | / | 78 | 46 |
| | 7 | 103 | 176 | 73 | 83 | 139 | / | 0 | 175 |
| | 8 | 91 | 33 | 18 | 130 | 167 | / | 76 | 0 |
| | 9 | 60 | 64 | 56 | 12 | 55 | / | 85 | 50 |
| | 10 | 55 | 153 | 120 | 2 | 13 | / | 10 | 21 |
| Job 3 | 1 | 0 | / | 95 | 71 | 53 | / | 134 | 141 |
| | 2 | 55 | / | 94 | 125 | 107 | / | 79 | 60 |
| | 3 | 86 | / | 0 | 38 | 52 | / | 9 | 73 |
| | 4 | 66 | / | 138 | 0 | 65 | / | 72 | 110 |
| | 5 | 82 | / | 89 | 113 | 0 | / | 40 | 80 |
| | 6 | 167 | / | 61 | 80 | 71 | / | 101 | 106 |
| | 7 | 65 | / | 1 | 85 | 52 | / | 0 | 179 |
| | 8 | 128 | / | 131 | 90 | 31 | / | 60 | 0 |
| | 9 | 73 | / | 2 | 6 | 104 | / | 101 | 137 |
| | 10 | 131 | / | 169 | 12 | 31 | / | 119 | 21 |
| Job 4 | 1 | 0 | 132 | 117 | / | 14 | 133 | 23 | / |
| | 2 | 49 | 0 | 94 | / | 19 | 163 | 71 | / |
| | 3 | 112 | 173 | 0 | / | 161 | 87 | 114 | / |
| | 4 | 154 | 115 | 77 | / | 8 | 131 | 7 | / |
| | 5 | 97 | 113 | 174 | / | 0 | 78 | 163 | / |
| | 6 | 5 | 119 | 117 | / | 100 | 0 | 45 | / |
| | 7 | 173 | 40 | 118 | / | 12 | 146 | 0 | / |
| | 8 | 43 | 178 | 19 | / | 137 | 75 | 63 | / |
| | 9 | 3 | 164 | 164 | / | 43 | 73 | 162 | / |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 | 55 | 58 | 46 | / | 18 | 109 | 40 | / |

**Job 5**

| Worker | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | / | 4 | 6 | 11 | / | 2 | 112 |
| 2 | 120 | / | 26 | 160 | 150 | / | 126 | 64 |
| 3 | 5 | / | 0 | 104 | 35 | / | 121 | 130 |
| 4 | 107 | / | 59 | 0 | 5 | / | 76 | 77 |
| 5 | 139 | / | 177 | 157 | 0 | / | 127 | 29 |
| 6 | 61 | / | 48 | 105 | 18 | / | 112 | 154 |
| 7 | 5 | / | 17 | 63 | 91 | / | 0 | 72 |
| 8 | 80 | / | 123 | 111 | 104 | / | 21 | 0 |
| 9 | 81 | / | 25 | 177 | 84 | / | 128 | 57 |
| 10 | 129 | / | 20 | 166 | 63 | / | 26 | 33 |

**Job 6**

| Worker | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 130 | 74 | / | 131 | 80 | / | 129 |
| 2 | 136 | 0 | 127 | / | 5 | 74 | / | 126 |
| 3 | 148 | 99 | 0 | / | 116 | 9 | / | 58 |
| 4 | 15 | 72 | 62 | / | 131 | 165 | / | 4 |
| 5 | 105 | 68 | 116 | / | 0 | 30 | / | 44 |
| 6 | 43 | 163 | 112 | / | 92 | 0 | / | 5 |
| 7 | 5 | 2 | 23 | / | 161 | 102 | / | 159 |
| 8 | 152 | 30 | 26 | / | 140 | 106 | / | 0 |
| 9 | 141 | 133 | 128 | / | 167 | 18 | / | 141 |
| 10 | 21 | 61 | 146 | / | 57 | 145 | / | 29 |

From Table 5, we calculate the total training cost of the worker for each worker. This is shown in Table 6. In Table 7, is defined the worker-to-hub assignment plan by assigning workers to the respective hubs based on their training costs. In Table 7 the number "1" denotes the allocation exists, "0" denotes the allocation does not exist.

**Table 6**. The total cost incurred for each worker on training each Job type.

| Worker | Job 1 (Hub1) | Job 2 (Hub 2) | Job 3(Hub 3) | Job 4(Hub 4) | Job 5 (Hub 5) | Job 6(Hub 6) |
|---|---|---|---|---|---|---|
| 1 | 434 | 497 | 702 | 528 | 233 | 719 |
| 2 | 562 | 606 | 734 | 668 | 824 | 615 |
| 3 | 374 | 729 | 344 | 896 | 545 | 639 |
| 4 | 785 | 553 | 575 | 675 | 391 | 688 |
| 5 | 537 | 685 | 607 | 716 | 825 | 496 |
| 6 | 504 | 605 | 713 | 551 | 550 | 647 |
| 7 | 873 | 801 | 443 | 539 | 341 | 539 |
| 8 | 684 | 575 | 569 | 773 | 608 | 543 |
| 9 | 724 | 450 | 501 | 671 | 646 | 742 |
| 10 | 604 | 374 | 629 | 367 | 487 | 519 |

**Table 7.** The worker-to-Hub assignment plan

| Worker | Hub 1 | Hub 2 | Hub 3 | Hub 4 | Hub 5 | Hub 6 |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 1 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| 6 | 1 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 1 |
| 9 | 0 | 1 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 1 | 0 | 0 |

**Table 8.** The difference of total training cost for worker $i$

| Worker | Hub 3 | Hub 4 | Hub 2 |
|---|---|---|---|
| 1 | 469 | 295 | 264 |
| 2 | 172 | 106 | 44 |
| 4 | 184 | 284 | 162 |
| 5 | 111 | 220 | 189 |
| 6 | 209 | 47 | 101 |
| 7 | 102 | 198 | 460 |
| 8 | 26 | 7 | 32 |

**Table 9.** The data of workers' level of skill before training the workers ( $\beta_{ni}$ )

| Workers | Job Types | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 5 | 6 | 7 | 10 | 9 | 8 |
| 2 | 5 | 9 | 5 | 5 | 8 | 5 |
| 3 | 9 | 6 | 9 | 6 | 5 | 10 |
| 4 | 6 | 8 | 8 | 9 | 5 | 10 |
| 5 | 5 | 6 | 9 | 6 | 7 | 7 |
| 6 | 10 | 5 | 10 | 7 | 6 | 5 |
| 7 | 10 | 9 | 10 | 10 | 9 | 8 |
| 8 | 6 | 5 | 7 | 10 | 6 | 5 |
| 9 | 9 | 10 | 6 | 6 | 5 | 8 |
| 10 | 10 | 7 | 7 | 8 | 6 | 9 |

Table 8 shows that number of worker in Hub 1 exceeding the predefined Hub size 2. Thus, we have $S_s = \varphi$ and $S_w = \{1, 5, 6\}$. The numbers inside the curl bracket represents Hub 1, Hub 5, Hub 6 respectively. According to worker to hub allocation plan (Table 7), from step 2 in stage 3, so as to calculate the difference of total training cost, we can remove few workers from hub's 1, 5 and 6 to hub's 3, 4 and 2. Hereby, workers were transferred to the hubs that have high workloads on it. Table 9 shows skill levels of each worker before the training was given and it also enlightens where their skills are lacking.

**Table 10**. The adjusted worker-to-hub allocation plan

| Worker | Hub 1 | Hub 2 | Hub 3 | Hub 4 | Hub 5 | Hub 6 |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 1 | 0 | 0 | 0 |
| 4 | 0 | 1 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 1 |
| 6 | 1 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 1 |
| 9 | 0 | 1 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 1 | 0 | 0 |

**Table 11**. All feasible operation-to-worker training plans.

|  | Worker | Op -1 | Op -2 | Op-3 | Op-4 | Op-5 | Op-6 | Op-7 | Op-8 | Op-9 | Op-10 | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hub 1 | 2 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 326 |
|  | 6 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |  |
| Hub 2 | 4 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 338 |
|  | 9 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |  |
| Hub 3 | 3 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 344 |
| Hub 4 | 10 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 367 |
| Hub 5 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 109 |
|  | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |  |
| Hub 6 | 5 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 280 |
|  | 8 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |  |

The Table 10 is the adjusted worker to hub assignment plan which is obtained after optimizing the number of workers in each hub according to the predetermined size. In Table 11, $Tc$ indicates total cost incurred for training all the workers in the particular hub, and $Dj$ represents the sum of squares of deviations from mean of operating times among the workers in the respective hubs. After completion of training, there is a gradual decline in operating time of each worker when compared to the period workers were trained.

## 6. Conclusions and future work

In this paper, we have proposed a distributed manufacturing based Telefacturing approach for better collaboration and coordination of enterprises which are geographically distributed and to proper allocation of hubs (Common work places) for the workers who are capable of performing multiple jobs in a single work place. In order to achieve this and to enhance the interoperability this research work is carried out in two phases. Firstly, by using Protégé software, Ontology based knowledge was created where the meaningful information is sent across the platforms in an effective manner. In addition, this tool has the capability to transform

stored Ontology data into XML/ RDF files. The generated XML files enable the possibility of sharing information within the heterogeneous network system without any conflicts. With this transferred information the Integration of Process Planning and Scheduling has been performed by minimizing the makspan as one of the objective for effective and efficient manufacturing system. Moreover, through queries, a platform for accessing large database in real time was developed. Secondly, in the proposed environment there is a flexibility to work for multiple operations in a single work place and this can be supported with help of multi-skilled workers. Therefore, prior to working in the actual environment workers are given training that enhances their capability into semi-skilled to multi-skilled workers. It is necessary to validate the proposed approach, thus a real case with an illustrative example is taken and it has been applied in an actual manufacturing environment. Here, minimization the processing time of the workers' thereby total cost reduction in the hub is considered as our second objective. As the problem is complex in nature we have used an evolutionary algorithm based approach and also developed a heuristic algorithm to find the best possible results for the above mentioned objectives. Finally, the results indicate the effectiveness of the proposed approach on the considered manufacturing system and also readiness to implement the hubs in near future. In future, this approach can be implemented in geographically located small and medium scale enterprises and also the possibility of creating more hubs can be investigated. In addition, one can use mobile agent based approach to solve this approach more effectively.

**Conflict of Interests**

The authors declare that there is no conflict of interest regarding the publication of this paper.

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